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PENGARUH KEGIATAN PERTAMBANGAN BATUBARA TERHADAP PERUBAHAN PARAMETER HIDROLOGIS

THE EFFECT OF COAL MINING ACTIVITIES ON HYDROLOGICAL PARAMETER CHANGE

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Abstrak

Pertambangan merupakan kegiatan konvensional yang mengubah bentang alam dan menyebabkan perubahan parameter hidrologi dan gangguan lingkungan, seperti terhambatnya pertumbuhan vegetasi akibat penurunan muka air tanah, rusaknya lahan produktif yang berdampak pada aliran sungai, pencemaran air, penggundulan hutan, dan erosi. Pembukaan lahan untuk kegiatan penambangan batubara berpotensi merusak struktur lapisan tanah, akibat hilangnya vegetasi penutup tanah, sehingga terjadi perubahan parameter hidrologi antara lain penurunan aliran dasar sebesar 11,79% (50,55 mm), peningkatan limpasan langsung sebesar 40,35% (273,73 mm), 21,92 mm. % (250,30 mm) peningkatan limpasan permukaan, penurunan infiltrasi sebesar 15,73% (76,21 mm), peningkatan evapotranspirasi potensial sebesar 11,03% (122,52 mm), sehingga menyebabkan debit sungai berfluktuasi. Setiap 10 Ha pembukaan lahan untuk kegiatan pertambangan menyebabkan peningkatan limpasan sebesar 51,46% (291,36 mm). Sementara itu, kegiatan pascatambang, termasuk reklamasi dan vegetasi, hanya mampu menurunkan aliran dasar sebesar 6,95% (5,95 mm) dan meningkatkan limpasan langsung, limpasan permukaan, infiltrasi, dan evapotranspirasi potensial sebesar 9,36% (89,11 mm), 11,19% (148,20 mm).), masing-masing 3,81% (15,56 mm), dan 1,73% (21,34 mm). Selain itu, setiap 10 Ha area reklamasi berhubungan dengan penurunan limpasan sebesar 47,22% (264,62 mm).

Kata Kunci: *Baseflow, Direct Runoff, Runoff, Infiltration, and Evapotranspiration*

Abstract

Mining is a conventional activity that alters the natural landscape and causes hydrological parameter changes and environmental disruptions, such as hampered vegetation growth due to water table subsidence, damaged productive land that affects the river flow, water pollution, deforestation, and erosion. Land clearing for coal mining activity potentially damages the soil layer structure, due to the loss of ground cover vegetation, so hydrological parameter changes, including an 11.79% (50.55 mm) decreased base flow, 40.35% (273.73 mm) increased direct runoff, 21.92% (250.30 mm) increased surface runoff, an 15.73% (76.21 mm) decreased infiltration, 11.03 % (122.52 mm) increased potential evapotranspiration, causing fluctuating river debit. Every

10 Ha of land clearing for mining activities related to 51.46% (291.36 mm) increased runoff. Meanwhile, the postmining activities, including reclamation and vegetation, could only decrease the baseflow by 6.95% (5.95 mm) while increasing the direct runoff, surface runoff, infiltration, and potential evapotranspiration by 9.36% (89.11 mm), 11.19% (148.20 mm), 3.81% (15.56 mm), and 1.73% (21.34 mm), respectively. Furthermore, every 10 Ha of reclamation area is related to an 47.22% (264.62 mm) decrease in runoff.

Keywords:
Baseflow, Direct Runoff, Runoff, Infiltration, and Evapotranspiration

1. INTRODUCTION

Since Law no. 3 of 2020, in lieu of law No. 4 of 2009 on mineral and coal mining, states that minerals and coal are national wealth and among Indonesia's potential natural resources, and their management is under the central government's control. However, the regional governments are expected to obtain more benefits from this stipulation (Al Farisi, 2021). From an economic perspective, the presence of a mining company may positively affect social development and productivity (Soelistijo, 2012) and is always linked to corporate *social responsibility* involving five aspects: community relationship, community empowerment, structure development, natural disasters, and operational aspect (Oktarinasari et al., 2021). Mining is a conventional activity that alters the natural landscape and causes hydrological parameter changes and environmental disruptions, such as hampered vegetation growth due to water table subsidence, damaged productive land that affects the river flow, water pollution, deforestation, and erosion (Khobragade, 2020). Soil erosion can decrease the water availability for vegetation growth, leading to decreased plant ecosystem population (Moreno-de las Heras, 2009), which is primarily caused by excessive rainfall, lack of soil management, and chemical exposure from mining activity. Meanwhile, mines in forest areas are responsible for ecosystem and habitat damage (Wantzen & Mol, 2013). Mining activities that do not follow the standard operating procedure will damage the water and impair the ecosystem's ability to perform its function as the water system protector and weather regulator, thus causing drainage patterns and climate changes.

2. RESEARCH METHODOLOGY

Location and Time

The study was conducted in a coal mine PT. Bukit Baiduri in a mining business permit area in East Kalimantan from December 2021 to September 2022 (Figure 1).

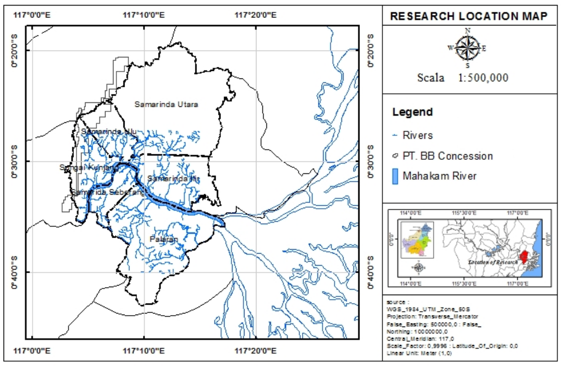

Figure 1. Research Location Map

Rainfall Data analysis

Climate and rainfall are highly non-linear and complex phenomena that requires a classical approach(T.O.Olatayo & Taiwo, 2014) and an important element for understanding the role of the hydrological cycle and hydrological engineering (Vijay P. Singh, 2016). One of the main elements of the hydrological cycle is precipitation, which acts as the main cause of runoff (Mishra et al., 2013).

Rainfall is an important aspect to estimate the water availability for a hydrological process (Yin et al., 2015). In order to analyze the frequency and distribution of rainfall, the normal distribution is used as the continuous probability distribution function. In this regard, if the mean equals zero and the variance is 1, the distribution is deemed normal (Maity, 2018) as follows *:*

$$P(X) = \frac{1}{\sigma\sqrt{2\pi}} . e^{\frac{1}{-2}(\frac{x-\mu}{\sigma})^2}$$

Description:
P(X) = normal density function, X = continuous random variable, μ = mean X σ = Standard deviation of X, π = 3.14156, e = 2,71828

Base Flow

Base flow is a part of river flow that is maintained between rainfall events, and fed to the river by the delayed line (Hopmans, 2000). Base flow in a catchment area is vital as it may affect various aspects of water resource management, such as water use, water quality, and low flow prediction (Kissel & Schmalz, 2020). Deforestation and vegetation and soil changes may cause a low flow change. (W. Liu et al., 2015). *Groundwater storage* (ΔGS) refers to a difference between *groundwater storage* in the observed month and *the groundwater storage* in the previous month. Changes in groundwater storage are pivotal for baseflow formation. In this regard, baseflow is a difference between the infiltration and groundwater storage changes in the form of an equation (Field, 2005) :

BF = I – GS

Description:
BF = Base Flow, GS= Groundwater Storage,
I = Infiltration

Direct Runoff

Some of the rainwater does not turn into the surface flow, as they are held by vegetation (Shadeed & Almasri, 2010). The SCS-CN method is a common empirical approach for calculating direct runoff of a rainfall event from the watershed in the form of a small agricultural area, forest and urban area, or even a combination of several characteristics of the watershed(Soulis et al., 2009), allowing the direct runoff to be calculated using the following formula :

DRO = WS – I

Description :
DRO = Direct Runoff, WS =Water Surplus, I=Infiltration

Runoff

Runoff is a portion of rainwater that flows on the land surface toward rivers, lakes, or seas (H. Li et al., 2015). It occurs when the land cannot infiltrate the water on the surface due to its saturation state (Odiji et al., 2020). According to Oki et al. (2001), the total runoff that serves as a component forming a river discharge is a coefficient between the baseflow and the direct runoff, as stated in the following formula:

TRO = BF+DRO

Description :
TRO = Total Runoff, BF=Base Flow, DRO = Direct Runoff

Infiltration

Panahi et al. (2021) state that the infiltration coefficient is determined by the porosity and the flow gradient and occurs until it reaches the groundwater reservoir zone. Meanwhile, Q. Liu et al. (2021) state that, in general, the infiltration coefficient (if) used for low land is 0.3 while that for highlands is 0.5, and the k ranges about 0.5 and 0.6 for the lowland and the highland, respectively.

I = WS x if

Description:
I = Infiltration, WS = Water Surplus,

if = Infiltration coefficient

Potential Evapotranspiration

Potential evapotranspiration could be calculated using the Penman method, i.e., by calculating the climatological data, including air temperature, solar radiation, air humidity, and wind velocity, to ensure a more accurate result. Potential evapotranspiration is based on the assumption that evaporation needs heat to occur (Seiller & Anctil, 2016).

The potential evapotranspiration is calculated using the following formula:

$$E = \frac{AH + 0,27D}{A + 0,27}$$

Description:
E = monthly potential evapotranspiration (mm/month)
H = Budget energy = R (1-r) (0,18 + 0,55 S) – B (0,56 – 0,092 $\sqrt{ed}$) (0,10 + 0,9 S)
D = Heat needed for evapotranspiration = 0,35 (e_a – e_d) (k + 0,01 w)
A = The gradient of vapor pressure curve at the average temperature (mmHg/°F)
B = The surface radiation at the average air temperature (mmH_2O/day)
e_a = Saturated vapor pressure at the average temperature (mmHg)
R = Solar radiation on the horizontal surface above the atmosphere (mm/day)
r = Reflection coefficient
S = The average percentage of monthly sunlight, in percentage (%)
e_d = Actual vapor pressure, in mmHg. (Ea x h)
h = The average relative monthly humidity, in percent (%).
k = Roughness coefficient of evaporation surface.
For water surface = 0.50 and vegetation surface = 1.0.
w = average wind velocity in mile/day.

Actual Evapotranspiration

Actual evapotranspiration occurs in a limited water condition, which is affected by the proportion of exposed surface during the dry season (Jung et al., 2016). The difference between potential and actual evapotranspiration is affected by the exposed surface (m) and the number of rainy days. Thus, the potential evapotranspiration will be equal to the actual ones. If the evapotranspiration occurs in the primary or secondary forest, the value of the exposed surface is equal to zero (Wayan Sutapa et al., 2021).

Setiadi et al. (2022) state that the number of rainy days in an area is equal to 18 days. Thus, the difference between potential and actual evapotranspiration is affected by the exposed surface and the rainy days, as shown in the following formula :

$$\frac{\Delta E}{E_p} = \left(\frac{m}{20}\right)(18 - n),\ \Delta E = E_p\left(\frac{m}{20}\right)(18 - n),\ E_a = E_p - \Delta E$$

Description:
Ea = actual Evapotranspiration Ep = potential evapotranspiration, m = exposed surface n = number of rainy days

3. RESULT AND DISCUSSION

Hydrological condition

a. Baseflow

Baseflow represents the amount of water discharged to a river or a lake, which could be affected by surface runoff, direct runoff, and infiltration (Mo et al., 2021). The baseflow analyses before, during, and after the mining activities (Table 1) showed that the exposed surface could decrease the baseflow by 11.79% (50.55 mm) from the initial condition. This change is caused by denser surface condition due to mining operation that is responsible for relatively lower absorption. The post-mining activities could only increase the base flow by 6.95% (6.95 mm).

Table 1. Baseflow fluctuation

Bulan	Baseflow (mm)		
	Unmined Area	Mining Area	After Mined Area
Jan	30.8	26.82	27.12

Feb	29.33	26.91	27.55
Mar	56.23	50.23	55.19
April	60.13	55.79	58.21
May	57.45	50.46	55.15
Juny	37.21	34.56	36.25
July	28.12	25.44	26.57
August	25.32	20.9	23.41
Sept	15.77	12.62	14.41
Oct	17.76	12.84	15.94
Nop	58.21	51.57	57.33
Dec	68.22	65.27	66.41
Year	**484.55**	**433.41**	**463.54**

b. Direct Runoff

The amount of direct runoff will increase along with the infiltration decrease and increased water surplus (C. Li et al., 2018). Direct runoff has a relatively positive relationship with precipitation, where higher precipitation will likely result in larger runoff, and lower precipitation will likely result in lower runoff. Therefore, the precipitation changes will significantly affect the amount of direct runoff (Vannasy & Nakagoshi, 2016).

The analysis (Table 2) result showed that the mining activity could increase the direct runoff by 40.35% (273.73 mm). This is caused by a less porous soil surface, leading to low absorption and causing the rainwater to permeate and tend to run over directly. Meanwhile, the post-mining activities could only lower the direct runoff by 9.36% (89.11 mm).

Table 2. Direct Runoff Fluctuation

Bulan	Direct Runoff (mm)		
	Unmined Area	Mining Area	After Mined Area
Jan	55.78	98.23	90.23
Feb	87.35	127.31	119.71
Mar	75.21	111.77	99.25
April	68.56	98.21	88.59
May	26.1	45.12	39.36
Juny	19.74	27.66	24.15
July	14.88	28.65	18.41
August	5.00	17.00	12.00
Sept	6.24	29.27	12.45
Oct	94.54	118.87	109.17
Nop	105.64	153.17	125.76
Dec	127.5	160.73	151.22
Year	**678.39**	**952.12**	**863.01**

c. Surface Runoff

The amount of water that turns into runoff will depend on the intensity of rainfall, ground cover condition, slope gradient, ground type, and land management (Dumedah et al., 2021). Land clearing affects the water availability during dry season, while causing surface runoff during the wet season (Hu et al., 2020). The analysis result indicates that the land clearing for mining activities serves as one of the causes of the increased runoff discharge by 21.92% (250.30 mm), which decreases only by 11.19% (148.20) in the post-mining (Table 3).

Table 3. Surface runoff fluctuation

Bulan	Surface runoff (mm)		
	Unmined Area	Mining Area	After Mined Area
Jan	87.99	132.54	111.22
Feb	108.21	169.22	136.67
Mar	118.27	156.32	139.56
April	127.18	151.72	137.41
May	63.62	101.72	88.85
Juny	41.23	68.54	55.34
July	32.43	54.21	44.66
August	21.92	42.32	32.52
Sept	16.63	55.12	33.82
Oct	127.83	177.23	145.34
Nop	153.76	191.77	175.34
Dec	158.41	181.37	168.25
Year	**1141.6**	**1391.9**	**1243.7**

The simulation result (Table 4) demonstrates that every 10 Ha increase in mining area is related to a 51.96% (291.36 mm) increase in surface runoff with post-mining decrease of 47.22% (264.62 mm).

Table 4. Surface runoff fluctuation for every 10 Ha land clearing

Mining Area	Runoff (mm)		
	Unmined Area	Mining Area	After Mined Area
10 Ha	110.2	165.5	155.15
20 Ha	117.7	178.4	150.7
30 Ha	131.21	195.2	145.3
40 Ha	137.3	215.4	141.89
50 Ha	148.23	241.3	139.2
60 Ha	155.97	320.4	135.5
70 Ha	161.34	431.2	112.7
80 Ha	175.32	585.3	95.2
90 Ha	193.20	829.3	80.72
100 Ha	206.76	1288.8	65.47

d. Infiltration

Rainwater is not completely absorbed by the ground, and some turn into surface runoff and evapotranspiration (Singh et al., 2021). The infiltration rate depends on the ground condition, where it has high absorption, causes a larger infiltration rate, and gradually diminishes when the soil is water-saturated (Lederle et al., 2020). By assuming pre- and post-mining infiltration coefficients of

0.4 and 0.3, respectively, the result shows a decreased infiltration by 15.73% (76.21 mm) in a mining area, which increases by 3.81% (15.56 mm) after the mining activity (Table 5).

Table 5. Infiltration rate fluctuation

Bulan	Infiltration (mm)		
	Unmined Area	Mining Area	After Mined Area
Jan	51.18	12.1	23.25
Feb	59.93	23.54	30.62
Mar	56.45	20.56	32.12
April	49.65	22.36	31.91
May	28.17	10.54	21.21
Juny	18.18	6.86	11.43
July	12.01	2.68	7.43
August	17.20	0.79	4.54
Sept	25.43	4.36	15.89
Oct	83.44	26.54	38.56
Nop	71.34	24.45	53.76
Dec	78.83	34.17	51.23
Year	**484.26**	**408.05**	**392.49**

e. Potential Evapotranspiration

Potential evapotranspiration was measured using climatological data, including temperature, sunlight percentage, relative humidity, solar radiation, the reflection coefficient of the surface (albedo) and roughness (C. Liu et al., 2017). The result (Tabel 6) showed that the potential evapotranspiration in the mining area increases by 11.03% (122.52 mm) due to the loss of ground cover vegetation, causing the sunlight to directly radiate the ground surface and hence increases the ground surface and air humidity, which directly increases the evaporation. In the post-mining area, the potential evapotranspiration increases by 1.73% (21.34 mm).

Table 6. Potential Evapotranspiration Fluctuation

Bulan	Potential Evapotranspiration (mm)		
	Unmined Area	Mining Area	After Mined Area
Jan	78.21	98.88	90.63
Feb	99.45	121.39	116.71
Mar	91.23	110.21	105.44
April	90.77	105.28	100.29
May	87.22	100.12	97.78
Juny	79.73	92.45	88.32
July	90.43	108.22	101.19
August	79.54	101.33	98.39
Sept	86.44	103.55	100.28
Oct	92.39	109.84	107.12
Nop	80.61	102.87	100.47

Bulan	Potential Evapotranspiration (mm)		
	Unmined Area	Mining Area	After Mined Area
Dec	91.2	109.28	106.09
Year	**1110.44**	**1232.96**	**1211.62**

4. CONCLUSION

1. Land use change to mining area is responsible for changes in hydrological conditions and their parameter. In this study, the change to mining area is responsible for
   a. an 11.79% (50.55 mm) baseflow decrease;
   b. a 40.35% (273.73 mm) increase in direct runoff;
   c. a 21.92% (250.30 mm) increase in surface runoff;
   d. a 51.46% (191.36 mm) increased runoff for every 10 Ha land clearing for mining activities;
   e. a 11.03 % (122.53 mm) increase in potential evapotranspiration;
2. The post-mining activities including reclamation and revegetation could only result in:
   a. a 6.95% (5.95 mm) baseflow decrease;
   b. a 9.36% (98.11 mm) increase in direct runoff;
   c. an 11.19% (148.20 mm) increase in surface runoff;
   d. an 47.22% (264.62 mm) decreased runoff for every 10 Ha reclamation area;
   e. a 1.73% (21.34 mm) increase in potential evapotranspiration;
3. The land clearing for mining activities damages the subsurface soil layer structure, causing changes in the hydrological parameter values far from pre-mining states.
4. These changes occur because the coal mine tends to increase the air temperature and humidity, decrease baseflow, increase evapotranspiration, and increase the runoff coefficient closely related to the increased maximum debit in the river flow during the wet season and decreased minimum debit during the dry season, which are important hypothetical effect.

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